Technologies and Prospects for Fabricating NIF Targets

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ICF experiments and modeling during the past few years have lead to a better understanding of the growth of instabilities during capsule implosion, and the effects of instabilities on capsule performance. All current designs for ignition targets have solid D-T fuel layers on the capsule interiors, and a central issue for all capsule fabrication and cryogenic fuel layers is surface roughness. To assure ignition, the capsule and DT-ice surface roughness, as well as the radiation drive symmetry, must be small enough that there are no large departures from a spherical implosion. In the linear regime of instability growth, and assuming statistical independence, this condition is expressed by the quadrature sum:

$$\left(\frac{\sigma_{ice}}{\max \sigma_{ice}}\right)^2 + \left(\frac{\sigma_{cap}}{\max \sigma_{cap}}\right)^2 + \left(\frac{\text{drive asym.}}{\text{max drive asym.}}\right)^2 \leq 1$$

where the σ's are the rms roughnesses of the ice and capsule surfaces and "max" indicates the maximum value allowed for an ignition capsule, defined as the maximum imperfection in any of the three quantities that will give ignition, with the other two imperfections held at zero. A general objective is to reduce each of the three contributions to less than 0.25 and possibly as low as 0.1 to provide increased confidence in the likelihood of ignition.

Recent measurements of D-T ice surfaces formed on the interior of cylindrical containers with radii of curvature equal to that of NIF capsule designs, reported elsewhere[1], have demonstrated that the natural D-T layering process that has been termed "beta-layering" can provide surface features that are small enough that they will ignite in computer simulations. In these simulations, which include full 2-d radiation-hydrodynamic modeling of capsule implosions, max σ_{ice} was found to be about 3 μm for polymer ablators and about 6 μm for beryllium ablators. Actual measurements yielded roughly 1 μm surfaces. Additionally, several methods for improving these surfaces have been demonstrated, which provide margin for uncertainties in modeling and surface statistics, and allows ignition designs at possibly smaller drive energies. Some of these improvements are based upon the observation[2] that increasing the thermal gradient at the ice surfaces smoothes the surface as shown in

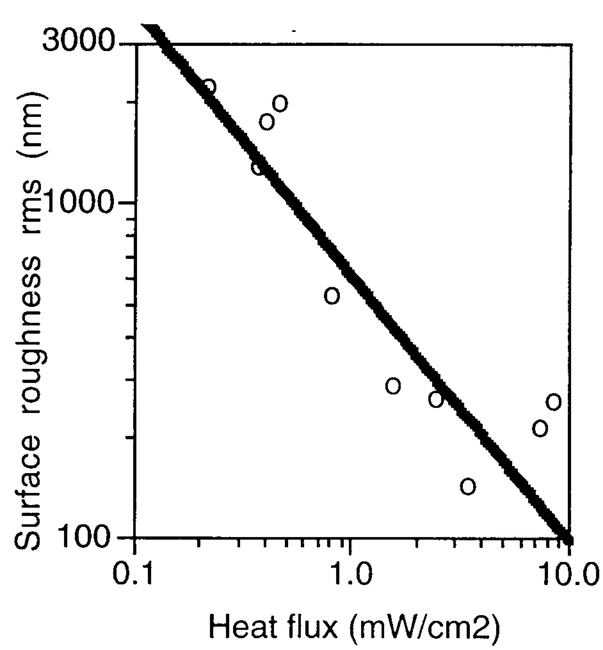

Fig. 1 Surface smoothing of solid deuterium by an impressed heat flux

Fig. 1. In capsules, increasing the thermal gradient is provided by additional bulk heating to the D-T solid by selective infrared absorption, or by subjecting the ice surface to a heat flux by heating the interior capsule vapor. In addition, we have found that growing the solid fuel layer on very low density polymer foam yields a smoother surface.

The implosion simulations have also shown that max σ_{cap} for polymer capsules is 50 nm. Fuel capsules used for current experiments on the Nova laser facility have surface morphologies that, if properly scaled to NIF sizes, are close to those required for ignition.[3] However, we do not yet have sufficiently smooth scaled surfaces that the capsule term in the quadrature sum is reproducibly less than 0.25, and solving this problem is crucial to ignition capsules. As seen in Fig. 2, atomic force microscopy characterization of the surface modes of Nova capsules shows that the predominant source of surface roughness is the lower modes (long wavelengths), which originate on coating mandrels. These are also the largest growing modes during implosion, and are the most difficult to control during fabrication. The liquid-drop-tower techniques used to make the mandrels are not easily scaled to NIF sizes (2 to 3 mm diameter), so new techniques are under development: microencapsulation, thermally decomposable coating mandrels, and a solid-precursor variation of the heated drop-tower method. A comparison of scaled power spectra from capsules produced by these techniques shows that they are similar to the Nova capsules produced by applying a plasma-polymer ablator to a drop-tower mandrel. However, further work is necessary to perfect one or more of these techniques for NIF scales. We have also begun to develop beryllium capsules by coating on a mandrel, and under certain circumstances have been able to produce beryllium shells that have sufficient porosity that they are diffusion fillable. This could be a considerable advantage over solid-density beryllium shells.

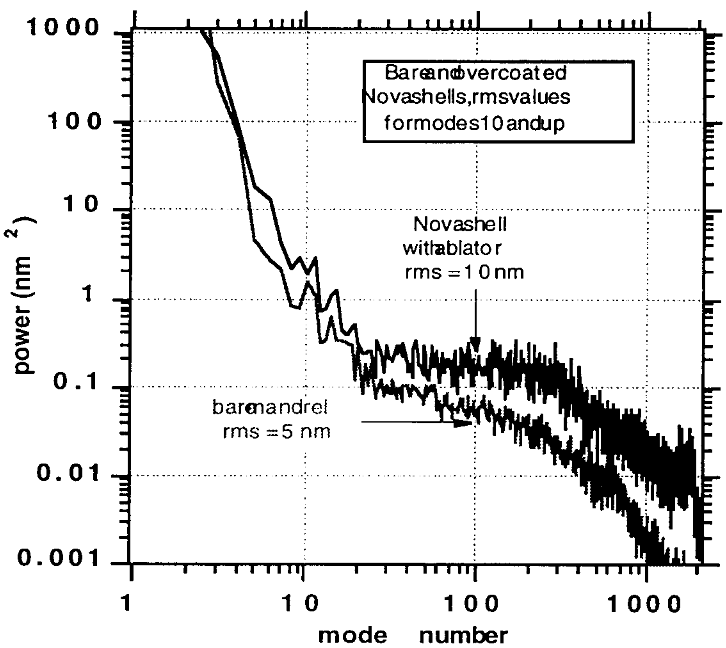

Fig 2. Mode power spectrum of Nova capsules. The majority of surface defects originate from low mandrel modes

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1 J. K. Hoffer et al. "Surface roughness measurements od beta-layered solid deuterium-tritium", Proceedings of the 24th European Conference on Laser Interaction with Matter, Madrid, 1996.

2 G. W. Collins, T. P. Bernat, W. A. Unites, E. R. Mapoles and C. Duriez, "Heat flux induced changes to multicrystalline D2 surfaces", in preparation.

3 R.C. Cook "Production of Hollow Microspheres for Inertial Confinement Fusion Experiments", Material Research Society Symposium Proceedings Vol. 372, p.101, 1995